Size Reduction of Printed Antenna Based on Spiral Resonator Incorporated with Matching Circuit for Performance Enhancement

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Abstract—**The development of wireless communication system often requires the device with compact size and light weight. To satisfy the requirement, the device should comprise of small parts, in which one of them is using printed antenna. Many researches on size reduction of printed antenna have been conducted. By using spiral resonator (SR) shape incorporated with matching circuit, in this paper, the size reduction of printed antenna is presented which is aimed to enhance the antenna performance. The proposed antenna is designed using two layers of 1.6mm thick FR4 dielectric substrate with a proximity coupled technique applied as the feeding system. It is found that the proposed technique offered the proposed antenna to have the S_{11} value of 25dB, the bandwidth of 40MHz, and the gain achievement of 2.3dBi. This is better than the performance of printed antenna without matching circuit which has the S_{11} value of 15dB, the -10dB bandwidth of 30MHz, and the gain achievement of -0.5dBi. Moreover, the size of proposed antenna is reduced significantly up to 60% compared to the conventional patch antenna.**

Keywords—Matching circuit; performance enhancement; printed antenna; size reduction; spiral resonator (SR).

I. Introduction

Recently, antennas which are frequently used in many wireless communication systems tend to have the characteristics of compact size and light weight. Various approaches in antenna miniaturization have been proposed by modifying the antenna geometry and/or applying the metamaterials [1]–[5]. There were also some researches related the use of MNG metamaterial in the planar antennas to reduce the dimension [6]–[8]. The MNG metamaterial has a shape of split ring resonator (SRR) and spiral resonator (SR). The SR structure has greater reduction factor compared to the SRR structure [1]. Thence, the SR structure could be very effective in reducing the size if implementing to the printed antenna.

Furthermore, in case of SR structure functioned as an antenna radiator, it must be connected to the feeding system. However, impedance matching at the feeding point was very hard to be satisfied. Therefore, the matching circuit is required for the feeding system yielding the improvement of antenna performance. In fact there are many constructions of matching circuit which could be implemented including the use of varactor and marchand balun [9]–[12]. However, to suit the antenna construction, the matching circuit should be constructed as simple as possible, for example, using interdigital capacitor (IDC) and meandered inductor (MI) that might be configurable in series and/or in parallel [10].

In this paper, size reduction of printed antenna which is designed based on SR structure incorporated with matching circuit is presented. Here, the use of matching circuit composed of IDC and MI is also aimed to enhance the performance of printed antenna. Two layers of 1.6mm thick FR4 dielectric substrate are used for deploying the proposed antenna. To shows the feasibility of performance enhancement, printed antennas with and without matching circuit are designed and analyzed through simulation. The design and analysis results are then validated by measurement setup for the fabricated antenna. Meanwhile, a conventional patch antenna is also designed to investigate the effect of size reduction and for comparison to the proposed antenna.

II. Spiral Resonator-based Printed Antenna

A simple SR structure with a square shape is applied for the design of printed antenna as illustrated in Fig. 1. As a radiator of antenna, the SR structure is required a feeding system to acquire the radiation performance. Here, the proximity coupled technique is proposed to feed the printed antenna. Hence, the printed antenna is then designed on two layers of dielectric substrate. The first layer is for deploying the antenna radiator which takes a SR shape, whereas the second one is for a feeding system which is electromagnetically coupled to the radiator and the groundplane. An FR4 epoxy dielectric substrate with the thickness of 1.6mm is used to deploy the design of printed antenna.

In fact, the proximity coupled feeding system is capacitive in nature of its coupling mechanism. This is in contrast to the direct contact methods, which are predominantly inductive.

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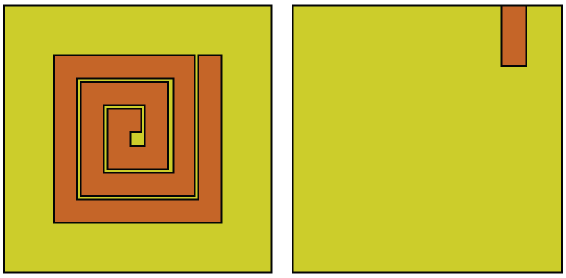

Fig. 1. Printed antenna based on SR structure; left is SR shape on top side of first layer; right is a feeding system on top side of second layer.

The difference in coupling type significantly affects the obtainable impedance bandwidth due to the inductive coupling of the edge and the probe-fed geometries limits the thickness of the useable dielectric substrate [10], [13]. The printed antenna is simulated for dimensional parametric of the spiral turn number (N) of 3, the strip width (w) of 3.1mm, and the gap width (s) of 0.5mm [10]. The simulation result shows that the value of reflection coefficient (S_{11}) of 15dB, the -10dB bandwidth of 30MHz, and the gain achievement of 0.5dBi at the frequency of 2.43GHz. It indicates that the obtained radiation performance is required to be improved. Hence, to enhance the radiation performance, a technique by inserting a matching circuit into the feeding system is introduced as shown in Fig. 2.

There are 2 types of matching circuit which are proposed for enhancing the radiation performance. Both matching circuits are designed using IDC and MI and positioned in the second layer of dielectric substrate. The first type comprises of 2 IDCs and 1 MI, while the second type has 2 IDCs and 2MIs. The investigation is limited for 2 different number of matching circuit components. The summary of simulated result of radiation performance for the proposed antenna, i.e. SR-based printed antenna incorporated with matching circuit, is tabulated in Table I with the printed antenna without matching circuit shown together as comparison. It is noticeable that the printed antenna with matching circuit Type 2 has the best radiation performance compared to the others. Meanwhile, Fig. 3 plots simulated radiation patterns for the printed antenna with and without matching circuit.

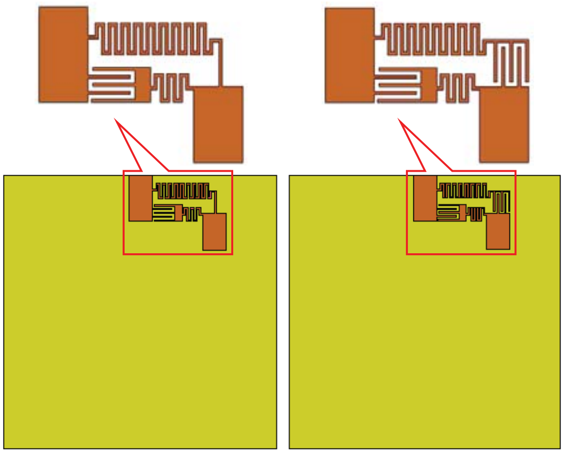

Fig. 2. Matching circuit designed using IDC and MI on top side of second layer; left is Type 1; right is Type 2.

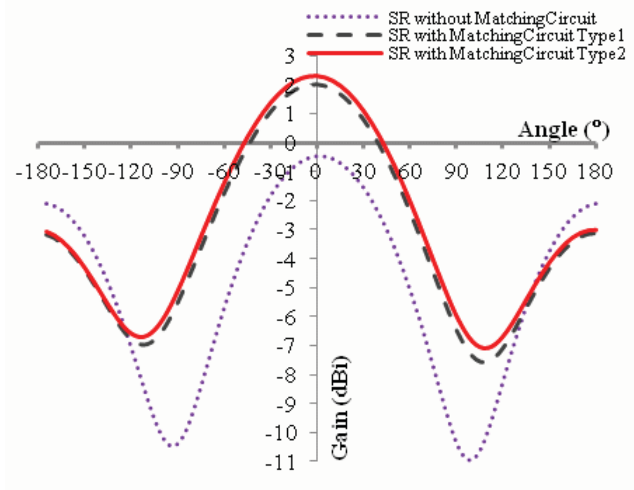

Fig. 3. Simulated radiation pattern for printed antennas.

Furthermore, to demonstrate the effect of size reduction, as shown in Fig. 4 a conventional patch antenna is investigated to be compared with the proposed antenna. The conventional patch antenna which is deployed on the same dielectric substrate, i.e. FR4 epoxy dielectric substrate, is designed to resonate at the same frequency of 2.45GHz. The simulated result of conventional patch antenna provides the S_{11} value of 23dB, the -10dB bandwidth of 70MHz, and the gain achievement

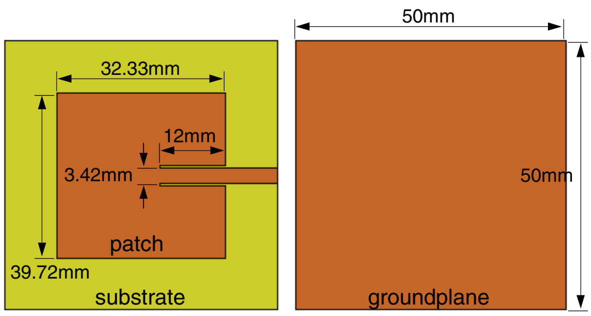

Fig. 4. Conventional patch antenna for investigation of size reduction.

TABLE I. RADIATION PERFORMANCE FOR PRINTED ANTENNA WITH AND WITHOUT MATCHING CIRCUIT (MC).

Parameter	without MC	with MC Type 1	with MC Type 2
Frequency (GHz)	2.43	2.46	2.45
S_{11} (dB)	-15	-14	-25
Bandwidth (MHz)	30	35	40
Gain (dBi)	-0.5	2.17	2.33

TABLE II. RADIATION PERFORMANCE FOR CONVENTIONAL PATCH ANTENNA AND PRINTED ANTENNA WITH MATCHING CIRCUIT TYPE 2.

Parameter	Conventional Antenna	Proposed Antenna
Patch dimension (mm^2)	39.72 × 32.22	22.6 × 22.6
Frequency (GHz)	2.45	2.45
S_{11} (dB)	-23	-25
Size reduction (%)	0 (reference)	60

of 3.1dBi at the frequency of 2.44GHz. Table II summarizes the comparison of radiation performance for the conventional patch antenna and the printed antenna with matching circuit Type 2. It can be inferred that the proposed antenna has the patch size of 510.76mm^2 which is much smaller than the conventional patch antenna size of 1282.31mm^2. It seems that the size reduction achieves up to 60% with some improvement in reflection coefficient value.

III. Fabrication and Measurement

The design results through simulation are validated by fabrication and measurement of printed antenna with matching circuit Type 2. Fig. 5 shows the picture of fabricated proposed antenna with a 50Ω connector attached into the edge of feeding system. The radiation performance of fabricated antenna which is characterized through measurement setup includes reflection coefficient, radiation pattern and bandwidth. The comparison of reflection coefficient between measurement and simulation results is depicted in Fig. 6. The measurement result shows a good agreement with the simulation result with a slight difference in resonant frequency and reflection coefficient. For convenience, the comparison between the measurement and simulation results of the proposed antenna performance, i.e. reflection coefficient (S_{11}), bandwidth, and gain achievement, are shown in Table III.

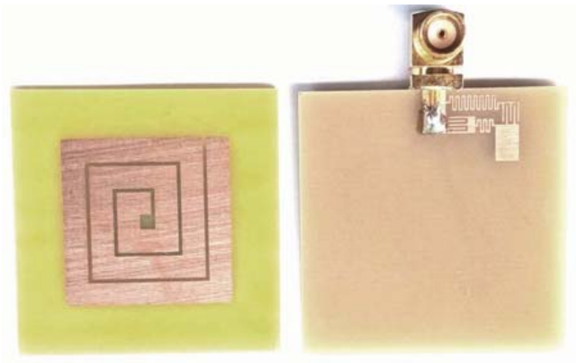

Fig. 5. Fabricated proposed printed antenna with matching circuit Type 2.

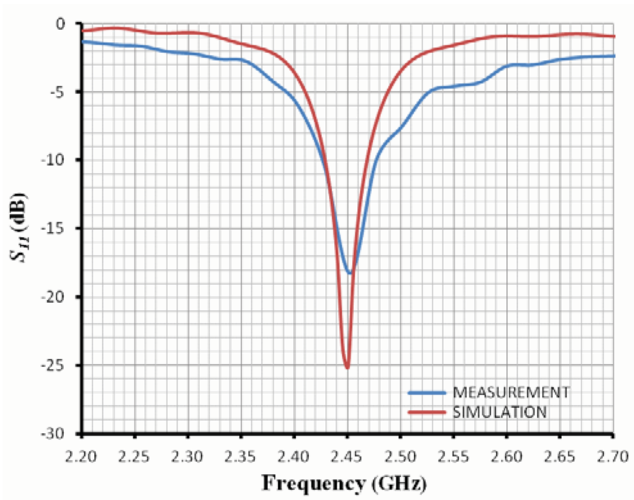

Fig. 6. Comparison of measured and simulated reflection coefficients.

TABLE III. Measurement and simulation results of proposed antenna performance.

Parameter	Simulation	Measurement
Frequency (GHz)	2.45	2.45
S_{11} (dB)	-25	-19
Bandwidth (MHz)	40	49
Gain (dBi)	2.3	2

For many antenna parameters such as dimensions, gain, and bandwidth, the compromise among these parameters is satisfied. In this case, the optimum value of proposed antenna parameters is achieved for the gain of 2.3dBi with a patch size reduction up to 60%. As aforementioned discussions, the printed antenna with SR shape has a unique structure with significantly size reduction. Therefore, the SR structure has good prospects to develop the printed antenna for applications of wireless communication systems.

IV. Conclusion

The printed antenna designed based on SR structure incorporated with matching circuit has been presented. It has been demonstrated that the matching circuit inserted into the feeding system could enhance the radiation performance of proposed antenna with the measured -10dB bandwidth of 49MHz and gain achievements of 2dBi at the frequency of 2.45GHz which was comparable to the simulated -10dB bandwidth and gain achievements of 40MHz and 2.3dBi, respectively. Meanwhile, the SR structure which was applied as the radiator of printed antenna could reduce the size of proposed antenna up to 60% compared to the conventional patch antenna.

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